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Teleoperator/Robot Technology Can Help Solve Biomedical Problems

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PREFACE

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TELEOPERATOR/ROBOT TECHNOLOGY CAN HELP SOLVE BIOMEDICAL PROBLEMS

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Abstract

Teleoperator and robot technology developed in recent years, particularly in space related programs, appears to offer the possibility to apply these techniques to the benefit for the severely handicapped (e.g., quadriplegics) giving them greater self reliance and independence. After identifying related needs in the United States, major problem areas in the development of prostheses and remotely controlled devices for the handicapped are briefly discussed, and the parallelism with problems in the development of teleoperator/robots identified. A short description is provided of some ongoing space and prosthetics related research and development work at JPL. Finally, a brief description of specific ongoing and projected developments in the area of remotely controlled devices (wheelchairs and manipulators) identifies possible near term accomplishments within the reach of the present state-of-technology.

Introduction

In 1968 the Department of Health, Education and Welfare reported that the rates of incidents of paralysis in the United States was 8.1 per 1000 population. This translates to a total of about 1.7 million paralyzed persons in the country. It was further reported that 60.9% of paralytics are severely limited in their capability to perform basic living activities. Thus, 1.04 million paralyzed individuals were at that time severely handicapped (Ref. 1).

In a study through the Office of Exploratory Research and Assessment of the National Science Foundation (Ref. 2), it has been determined that almost 10% of the total U.S. population is disabled. Table 1 indicates that nearly 3 million of these disabled Americans could be helped significantly with current rehabilitation technology. Many of the remaining 16 million are rehabilitable to a degree that would allow them to become productive individuals. Their rehabilitation would release trained therapists and aides to work with the more seriously disabled individuals who may not be rehabilitable with current technology. The question arises therefore how present technological capabilities and recent developments can be channelled and applied so as to help solve some related biomedical problems.

In 1970 NASA management initiated a program for the development of teleoperator and robot technology for space explorations and applications. Teleoperators have been defined as man-machine systems which extend man's sensory, manipulative and cognitive capabilities to remote places. The terms robot and robot system are used for the remotely controlled device of a teleoperator if it has autonomous motion or handling capabilities (Ref. 3). A review of related technology and potential applications in the space program has been given in Ref. 4. In addition, 41 articles in Ref. 5 present various aspects of teleoperator and robot applications and developments in space, in industry, under the sea, and in bioengineering. For instance, Peizer (Ref. 6) discusses certain application requirements for the spinal cord injured patient, and Rasor and Spickler (Ref. 7) project future teleoperator/robot applications in microsurgery, remote surgery, and remote health care.

A project jointly sponsored by the National Aeronautics and Space Administration and the Veterans Administration has recently been initiated at the Jet Propulsion Laboratory. The primary objective of this project is to apply teleoperator/robot technology to the rehabilitation of amputees and spinal cord injured patients with severe loss of motor, manipulative, and sensory capabilities in the upper and/or lower extremities. This paper attempts to give a systematic description of some major problem areas with emphasis of those requiring robot and teleoperator technology and to discuss related work at the Jet Propulsion Laboratory.

Major Problem Areas

To date conceivable substitutes for organs of the human body are biological (transplantations) or artificial (prostheses). Only prosthetic devices are of concern here. Their development problems can be categorized into four major areas: (1) material related problems including biocompatibility, strength, stiffness, weight, and wear resistance; (2) energy related problems including storage, conversion, and transmission of the required energy and power; (3) design related problems including determining the important functional requirements for the prosthetic device without causing undue complications in the configurational design and

Table 1 Estimate of disabled persons in the USA as of 1971 (Ref. 2)[a]

Disease Category	Total Number of Patients	Total Number in Rehabilitation Centers	Number of New Patients/Year	Percent Rehabilitable	Number that Could Be Helped With Current Technology
Stroke	2,000,000	250,000	500,000	60	400,000
Cerebral Palsy[b]	550,000	?	50,000	45	500,000
Multiple Sclerosis	500,000	?	50,000	?	50,000
Spinal Injuries[c]	100,000	1,000	10,000	95 (80 to jobs)	100,000
Amputees	350,000	?	?	100	350,000
Diabetes	3,000,000	?	?	?	600,000
Rheumatoid Arthritis	13,000,000	?	?	?	1,000,000
Totals	19,500,000	-	-	-	3,000,000

[a]Estimates supplied by Dr. James Reswick, Rancho Los Amigos Hospital, Downey, Calif., assembled from sources ranging from "hard" to "soft." Orders of magnitude appear correct.

[b]1956 figures

[c]Liberty Mutual estimates total cost for each quadriplegic patient ranges from $250,000 to $35[illegible]000; direct medical treatment costs range from $25,000 to $35,000 per patient, the remaining costs cover such things as workman's compensation, extended care, etc.

functional control; and (4) control related problems including sensing, deciding (either by man or computer, or both), command actuating, and command execution (either in an open loop or closed loop fashion).

The relative importance of each problem area from a development point of view depends on the prosthetic device. While material and energy related problems are of prime importance for artificial hearts, lungs, and kidneys, design and control related problems are of prime importance for artificial legs, arms, and hands. In particular the development of substitutes for the loss of the upper extremities demands the highest level of design and control technology, and completely satisfactory solutions have as yet not been found. It is expected that because of the many similarities of the functional requirements, teleoperator and robot technology including developments in manipulators, sensors, computers, machine intelligence, man-machine communication, etc. will help solve these most complex bioengineering problems. Another area expected to benefit even more directly from teleoperator and robot technology is the development of aides for the spinal cord injured handicapped (paraplegics and quadriplegics) potentially providing to them mobility and/or manipulative capability and hence greater self sufficiency. For instance, wheel chairs with attached manipulators or self-mobile robots with manipulators remotely controlled by the patient are under development or are planned to be developed.

The development of upper extremity prostheses and remotely controlled aids for the spinal cord injured brings together many of the essential areas that cybernetic systems (teleoperator/robot systems) must deal with to become practical. The following gives primary attention to problem areas of upper extremity prostheses and remotely controlled devices (RCD).

Command Inputs — The handicapped has only a limited bit rate of information available for control and command purposes. Estimates range from 50 bits for reading aloud to about 11 bits for ordinary motor activities. Amputees using non-manual outputs on the surface of the skin may achieve an output of the order of about 5 bits per second. One of the major problems here is to determine the appropriate level and type of information exchange between man and machine. Because of the individual, pathological and psychological aspects of each case (in contrast to the man-machine interface with a standard healthy person), this man-machine interface requires the greatest c[illegible]and attention to achieve patient acceptance [illegible]d eventual success.

Sensory Feedback — Adequate feedback from the prosthesis or RCD of its position and motion is of significant importance. Today the available feedback is primarily visual. For upper and lower extremity prosthesis, feedback occurs also through the force the prosthesis places on the stump or on the body. Feedback consisting of coded stimulation of the stump or other parts of the body requires learning on the part of the patient, and the use of the remaining afferent nerve signals presumes a breakthrough in nerval tapping techniques. In general, the transmission of feedback information other than visual has the same bit rate limitations quoted above for command inputs.

Autonomous Capability — The autonomous capabilities required for the prosthesis or RCD are related directly to the amount of information the person can exchange with the artifact. Going upward through the hierarchy of organization of man-machine symbiotic systems, the amount of information that can be transmitted to the machine decreases to the above quoted values. The level of required autonomous capabilities for the prosthesis or the RCD increases correspondingly for the same functional performance, requiring the application of technologies derived from machine intelligence and adaptive robot systems developments.

Performance — The quality of performance of prostheses or RCD's is strongly dependent on the functional designs. No reliable quantitative criteria and standards have as yet been developed. Prostheses should as much as possible replace the healthy limb. For instance, arm prostheses should be light weight (less than 3 Kg), should be able to generate high torques (about 70 N$\cdot$m elbow flexion), should provide high angular accelerations (several hundred rad/sec^2), and should provide rise times of a few milliseconds. With presently available hardware the level of performance one can expect from upper extremity prostheses are heavily constrained with respect to action time and precision execution. In addition, the healthy limb operates largely without conscious control, and therefore prostheses and RCD's should be designed to provide such capability to the greatest extent possible. They should be task oriented, imitative of human performance (not necessarily required for RCD's), adaptive to the sensed external environment, sensitive to modifications in the goals of the human operator (amputee or spinal chord injured person), able to learn tasks while these are being performed under visual feedback control, and sufficiently "intelligent" to provide to the handicapped the required help in a truly man-machine symbiotic manner.

This leads one to consider an approach to the solution of these problems that aims at developing prosthetic devices and remotely controlled aides for the handicapped which can accept higher level commands and which can independently perform some of the desired detailed tasks unless interrupted by a voluntary override.

Motivated by space application requirements, JPL is engaged in a teleoperator/robot research and development program with the objective to demonstrate through experimental simulations the feasibility of executing complex tasks in space under remote control with and without autonomous capabilities of the RCD. The technology, techniques, and procedures developed in this program are with appropriate modifications directly applicable to the development of upper extremity prostheses and, in particular, to the development of RCD's for helping the spinal chord injured quadriplegic to regain at least some of his lost self sufficiency.

Figure 1 shows schematically the essential elements of a teleoperator/robot system. The loop of information flow through the system (task space/environment - sensors - displays - human operator - control input - actuators - effectors - task space/environment) is in principle the same whether the application is in earth orbital space, on the moon, on Mars, an arm prosthesis, or a remotely controlled device (RCD) for the handicapped. However, the means of information transmission and the distances of transmission may be vastly different. Also, the level of required or desired independent action of the effectors as determined by the "computer" may vary considerably, and the prominence of certain system elements may be different from case to case.

Overview of Teleoperator/Robot Work at JPL

The Teleoperator/Robot studies at JPL have been initiated in 1971 with the objectives (a) to identify advanced research and development requirements, (b) to establish through laboratory simulations feasibility of advanced space exploration concepts, and (c) to demonstrate and evaluate the performance of required teleoperator/robot functions. Various sets of remotely controlled manipulators equipped with different terminal devices ("hands"), terminal sensors, man-machine interface display and command capabilities, and different levels of remote autonomous capabilities have been and are being investigated and developed at JPL.

In this Section, a short description is presented of remote control experiments using manipulator systems available at JPL. These experiments and man-machine breadboard efforts are directed to evaluate the performance of various control concepts including computer-aided supervisory control for the remote control of manipulators. The computer-aided supervisory control mode (Ref. 8) helps to overcome some of the operational problems caused by a physical barrier between the operator and the remote device by utilizing the best available capabilities of man and machine within an integrated control system.

A. Manipulator Systems at JPL

The JPL KOELSCH Robot system (Fig. 2) contains two identical arms mounted on a common shoulder link supported by a vertical post. The post is fixed to a small tread vehicle. The common shoulder link can be rotated about and raised along the vertical axis of the post. Relative to the common shoulder link, each arm has six basic

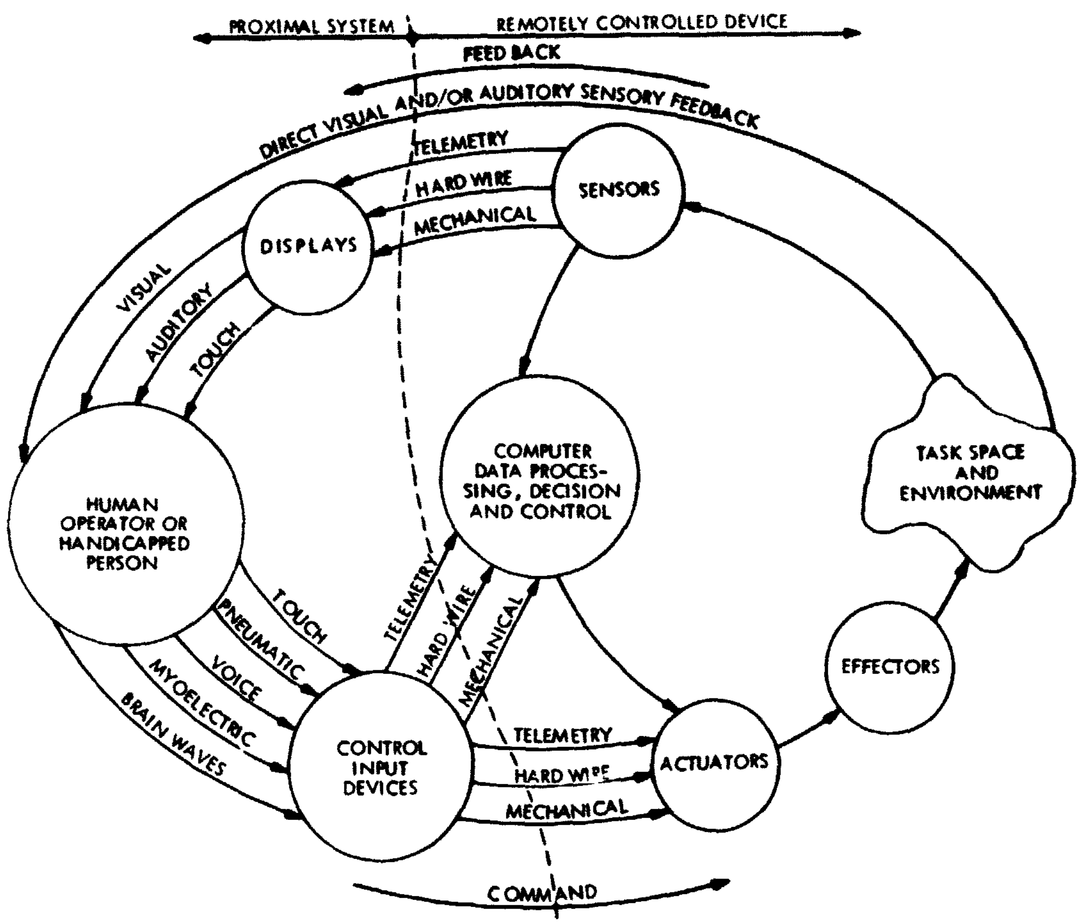

Figure 1. Schematic of Teleoperator/Robot System with Essential Elements and Communication Links

motion capabilities (six degrees-of-freedom): horizontal shoulder rotation, vertical shoulder swing, vertical elbow swing, vertical wrist swing, hand rotation, and hand grip. All joint motions are independent and can be operated individually or simultaneously in any direction. The servo system has both manual and computer control modes. The manual control is conventional rate control for each joint drive. The computer provides position control, but the drive servo loops are analog. Manual and computer control modes of operation are mutually exclusive. For remote control experiments, the Koelsch manipulator is equipped with a dual TV system mounted on the common shoulder link. The TV base has pan and tilt mechanisms. The identification of object coordinates is performed by the use of a cursor in the video display frame. Several sets of control experiments have been performed using the JPL KOELSCH Robot arm also using proximity sensors in both manual and computer control modes.

The NEVADA/CURV system (Fig. 3) consists of the CURV Linkage Arm mounted on a turret which can be rotated and elevated relative to the carrier vehicle, two TV cameras for stereo viewing, a separate TV camera for monodisplay, and a remote control station with RF or hardwired link to the vehicle-arm-TV system. This hydraulically powered arm has six degrees-of-freedom, plus opening and closing the hand mechanism. The essential and novel feature of this manipulator (Ref. 9) is that it provides true linear extension by the use of an idler gear of twice the radius of a forearm drive gear. Extension is achieved by moving the upper arm with respect to the idler. The linkage action causes the course traveled by the wrist during extension to be a straight line passing through both the azimuth and elevation axes. Elevation is achieved by rotating the whole mechanism about the axis of the idler. Azimuth is achieved by rotation about a vertical axis through the idler. A double parallelogram added to the linkage eliminates wrist disorientation during changes in elevation and extension of the arm. Thus, the arm performs the function of positioning the hand, without disconnecting it, in a spherical coordinate system. The arm has a high section modulus which makes it rigid but lightweight. The existing prototype can handle loads corresponding

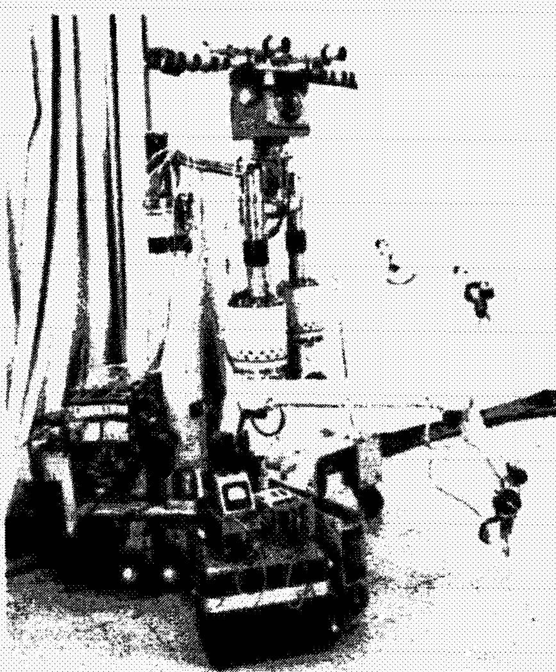

Figure 2. JPL KOELSCH Robot

to nearly 70% of the arm's weight at 1.5 m extension. The control system is presently a single on-off control for each joint. Rate control servo for joystick control and position control servo for computer control are under construction. The equipment of the hand with tactile, proximity, and force/torque sensors is also in process. Presently, the NEVADA/CURV system is used for hand-eye coordination experiments.

The JPL/AMES ARM (Ref. 10) is the outcome of a hard space suit design utilizing pseudoconic and stovepipe joints (Fig. 4). The arm has seven degrees-of-freedom, plus opening and closing the hand. The joints are electrically powered through harmonic drive gears. The basic control is position control in all control modes which are master-slave, independent joint control, tape, and computer control modes. Different types of hands can easily be interfaced with the arm, and controlled by switches from the master hand. In the master-slave control mode, the control is unilateral, that is, there is no force feedback from the slave to the master arm. The positioning accuracy of the arm measured at the fingertip at full arm extension is about 1 to 2 mm. Several sets of remote control experiments have been conducted with the JPL/AMES ARM in the master-slave control mode utilizing information from proximity sensors mounted to a parallel-finger

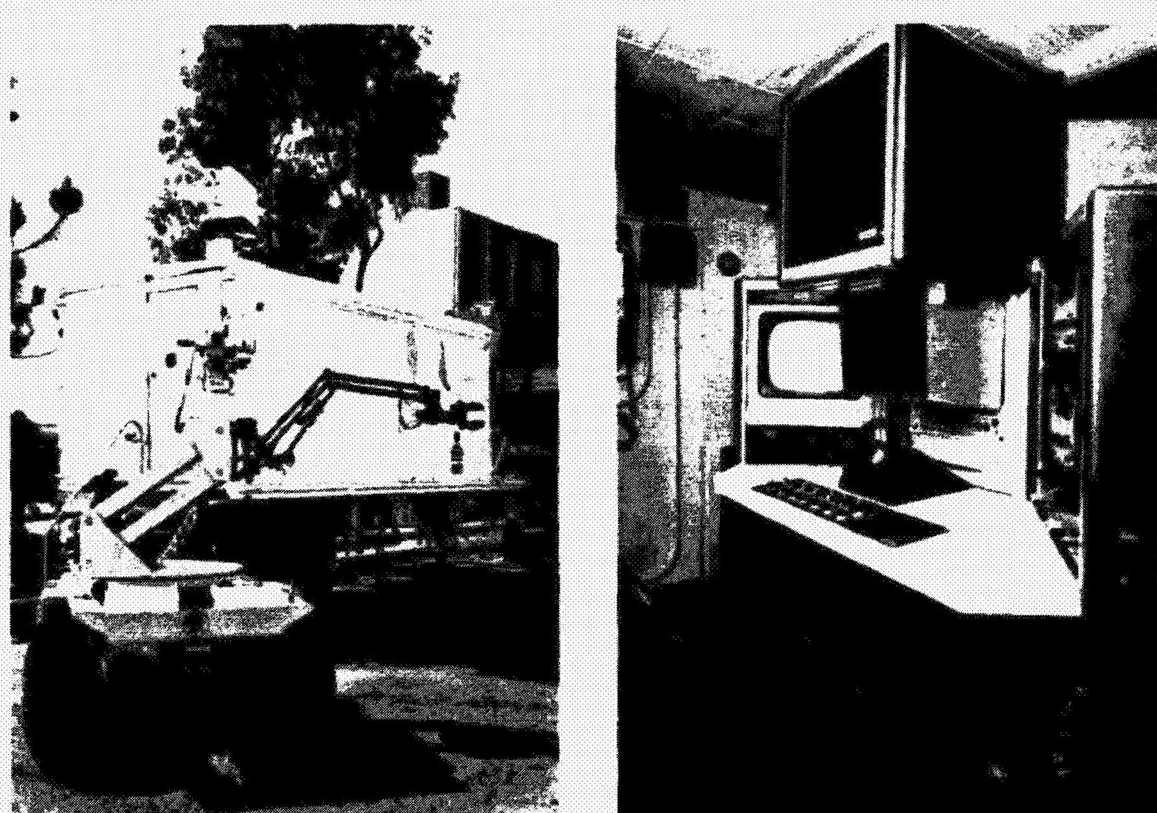

Figure 3. NEVADA/CURV System
Including Manipulator and Control Station
with Stereo and Mono TV Display

Figure 4. JPL/AMES ARM System

hand and displayed to the operator by audio and visual means.

Recently, an articulated and adaptively controlled humanoid hand has been added to the remote control experiments at JPL. Originally, the hand was developed for prosthetic applications and is described in detail in Refs. 11 and 12. The hand is interfaced with the seven degrees-of-freedom JPL/AMES ARM (Fig. 5), and controlled by a human operator in a proportional rate control mode. It is planned to interface the hand with different "external" sensors (tactile, slippage, and proximity sensors), and also use it under computer control.

The main characteristics of the hand follows (see also Fig. 6). The thumb and all four fingers are movable, and all phalanges on the fingers adapt themselves automatically to the shape of the grasped object. The hand is capable of two types of grasping: (1) bending the hand into a fist (fist mode), and (2) grasping with fingertips (pinch mode). The hand control has a built-in logic for semi-automatic selection of palmar or grasp prehension to suit the object. The hand has only one control site (one motor) for control input. A worm gear gives a self-locking property to the hand. The grasping force and the rate of finger motion are controlled proportionately.

There are obvious problems associated with the construction, use, and control of mechanical hands that are more dexterous than the commonly applied two-finger end effectors. Trade-off studies indicate, however, that the development and use of more dexterous mechanical hands would have considerable pay-off in many applications.

In addition JPL is engaged in a research program to develop artificial intelligence capabilities for the autonomous or semi-autonomous operation of planetary surface vehicle and manipulator systems. A description of some recent developments in this area is given in Refs. 13 and 14.

B. Remote Control Experiments at JPL

The general objectives of the remote control experiments at JPL are to study and develop techniques for generating, qualifying, and distributing the information flow and function allocation around the control loops of a remotely operated system. Of particular interest are the sensory data which supplement the visual information and

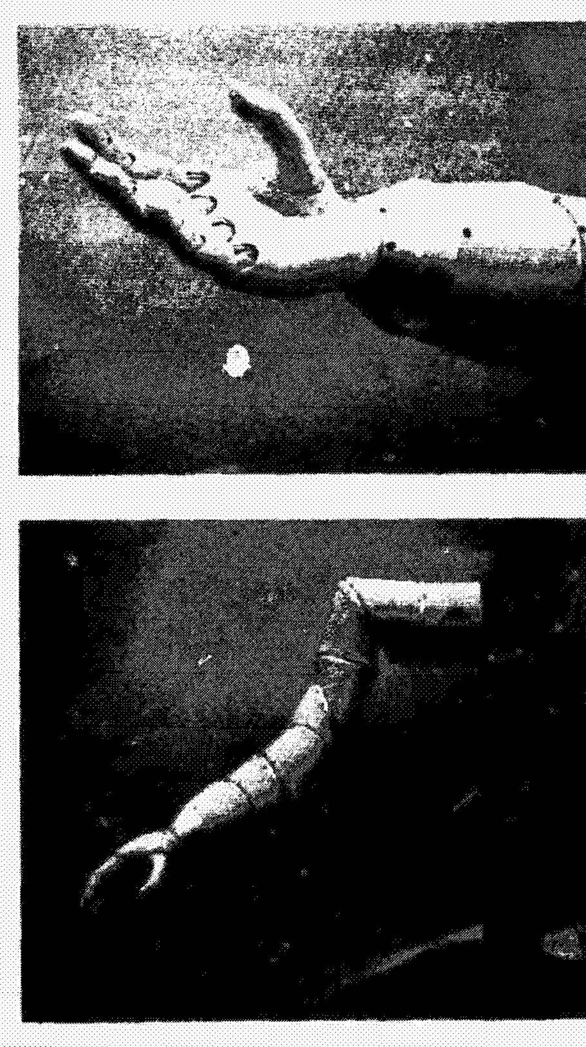

Figure 5. Humanoid Hand Attached to JPL/AMES ARM

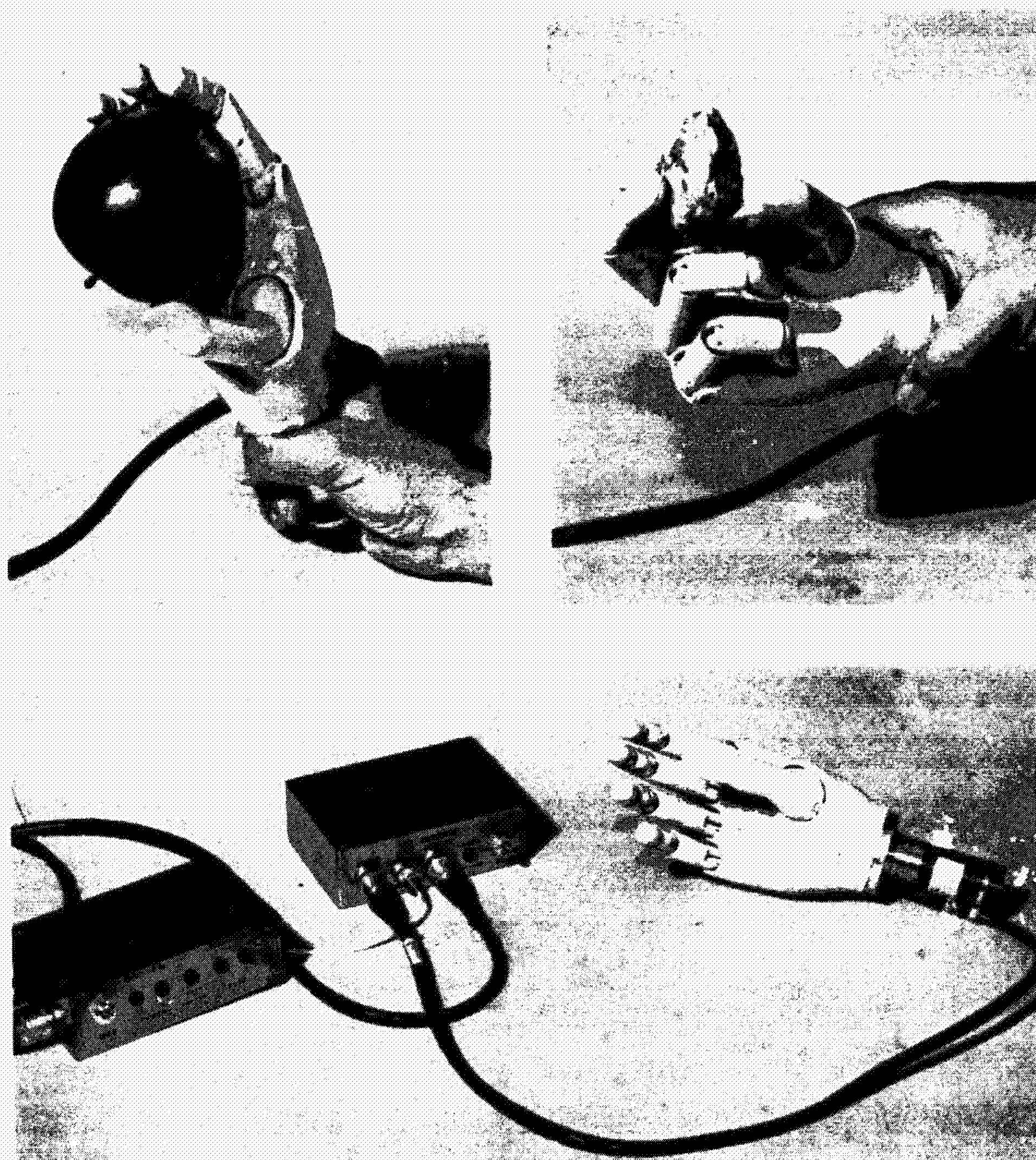

Figure 6. Humanoid Hand with Control Interface and Different Grasping Positions

immediately relate the manipulator's kinematical and dynamical state to the objects and environment.

The control experiments have been focused at the problems of "proximity control in manipulation" which, by definition, means the measurement and control of hand motion when the hand (with or without load and for any reason) has to move in the proximity of solid objects. To our knowledge, this particular problem has not yet received any specific attention elsewhere.

Proximity control utilizes a proximity sensor described in Ref. 15. The sensor concept is illustrated in Fig. 7. The sensor is a small electro-optical device with a small ellipsoid-shaped sensitive volume permanently focused at a distance of a few centimeters in front of the sensor. If this proximity sensor is mounted

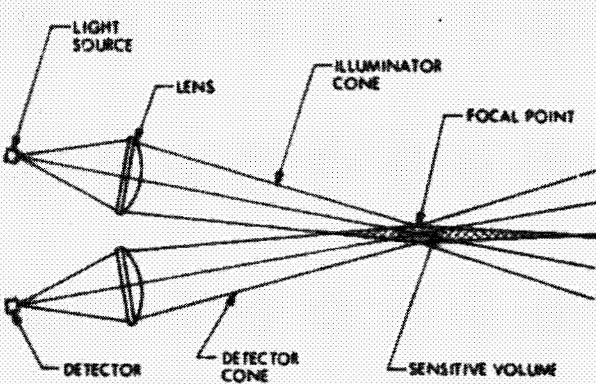

Figure 7. Proximity Sensor Concept

to the hand (or fingers), the sensitive volume will move with and ahead of the hand at a known distance relative to a reference point on the hand. When the sensitive volume "touches" a solid surface as the hand approaches the surface, the sensor generates a voltage signal which can be used to guide and control the approach motion of the hand in direct response to the sensed relative hand-object position and orientation.

A miniaturized version of the proximity sensor is shown in Fig. 8. This sensor does not have the optics shown in Fig. 7. The sensitive volume is therefore slightly larger resulting in a more diffuse definition of the geometry ahead of the sensor.

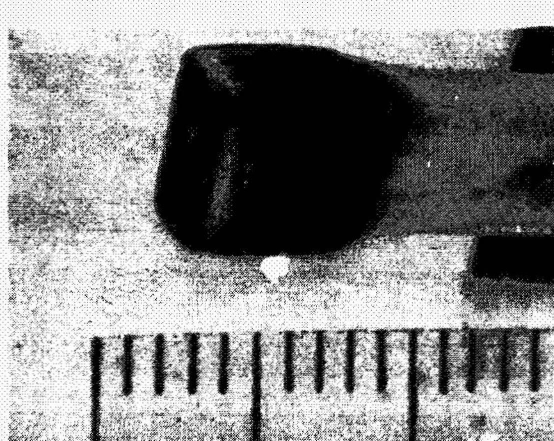

Figure 8. Mini-Proximity Sensor

In a series of remote control experiments, the JPL/AMES ARM is utilized in the master-slave control mode. The components of the experimental set-up are shown in Fig. 9. The master arm is in the remote control station, completely isolated from the workspace. The operator using the master arm for control inputs receives only visual information from the work scene in the form of stereo and mono-TV displays. The visual information is supplemented by audio tones generated by proximity sensors emplaced on the fingers as shown in Fig. 10. The control experiments have the specific objective to investigate the use of proximity sensor information by the operator for controlling the motion of the terminal device when the operator is a real-time element in the control loop. Clearly, the audio presentation of the proximity sensor signals requires that the operator understands and interprets the message of the signals in conjunction with stereo or mono-TV displays from the work scene since the signal's real meaning is "short distance" or a "range of short distances" in some specific direction of the work space. The control experiments have shown clearly that a video display of the work scene combined with an audio display of proximity sensor information can substantially enhance the operator's remote control capabilities. A detailed description and evaluation of the experiments will be published in a forthcoming paper.

In another series of remote control experiments, proximity sensors were interfaced with the hand of the JPL KOELSCH Robot (Fig. 2). The sensor signals were used in a computer control mode, manual (rate) control mode, and in direct (analog) control of one or two joint drives. A typical control problem is shown in Fig. 11. The operator in the remote control station views the work scene through a TV display. The scene presented to the operator is shown in Fig. 11a, where the camera looks almost vertically down. The same scene is also shown in a side view, Fig. 11b. This side view is generally not available to the operator. The task is to move the hand on top of the rock and pick it up. As shown in Fig. 11a, the viewing geometry for the task is quite disadvantageous since the arm/hand structure will obscure both the target and the neighboring obstacles in a top view as the hand moves above the target. In this control situation, the proximity sensor signal can provide sufficient guidance information to the controller to move the hand safely above the target. The controller can be a computer program which interprets the sensor signal so that the hand will move upward if obstacles are encountered. Alternatively, the control of one of the arm joint drives can be directly biased to the sensor signal so that the hand will move maintaining a fixed distance above the obstacles, while the operator controls the motion of the other joint. Or, the sensor signal can be displayed to the operator by audio or visual means so that the operator can determine what control action must be taken to avoid the obstacles. A detailed account of the different control experiments conducted with the Koelsch manipulator can be found in Ref. 16 and in a movie,

Fig. 9. Laboratory Set-Up for System Performance Experiments

Ref. 17. The remote control experiments have shown that proximity sensor applications to manipulator control can create useful feedback loops in any control mode, and will effectively supplement the feedback capabilities of other manipulator control techniques.

Encouraged by these results, more complex arrangements of mini-proximity sensors together with touch sensors are being developed and studied. Fig. 12 shows schematically such an arrangement on an artificial hand similar to the one shown in Figs.5 and 6. It is expected that designs along these lines will substantially increase the potential prehension capabilities of arm prosthesis.

Aids to the Severely Handicapped

As mentioned above, many of the technological problems of controlling teleoperator/robots in space, powered prosthesis and remotely controlled devices (RCD) for the handicapped are in principle the same. Much of the technologies, techniques and procedures can therefore be directly transferred. However, important differences exist which may easily render a project a failure if not properly taken into account. The primary difference is in the man-machine interface area. For space applications this interface is designed for the average (or above average) healthy operator, while in the prosthetics area it must be designed to accommodate the peculiarities of each individual case. Not only the engineering problems must be considered and solved, but, more important, the medical, psychological and asthetic aspects must find satisfactory solutions to achieve final patient acceptance. Thus, prostheses and remotely controlled aids for the handicapped can benefit from the achievements of teleoperator/robot technology primarily in the areas where similarities in the engineering requirements and techniques exist. The similarities can be classified into two categories: one is the hardware design, another is the control design. Hardware design for both applications encompasses such items as compatibility, dexterity, miniaturization, safety, reliability, and powering. The design of manipulator control in both applications is also faced with very similar technology requirements even though the nature of the physical barrier between man and equipment may be quite different in the two cases.

In both applications, the basic goal is to perform a maximum of different tasks using a

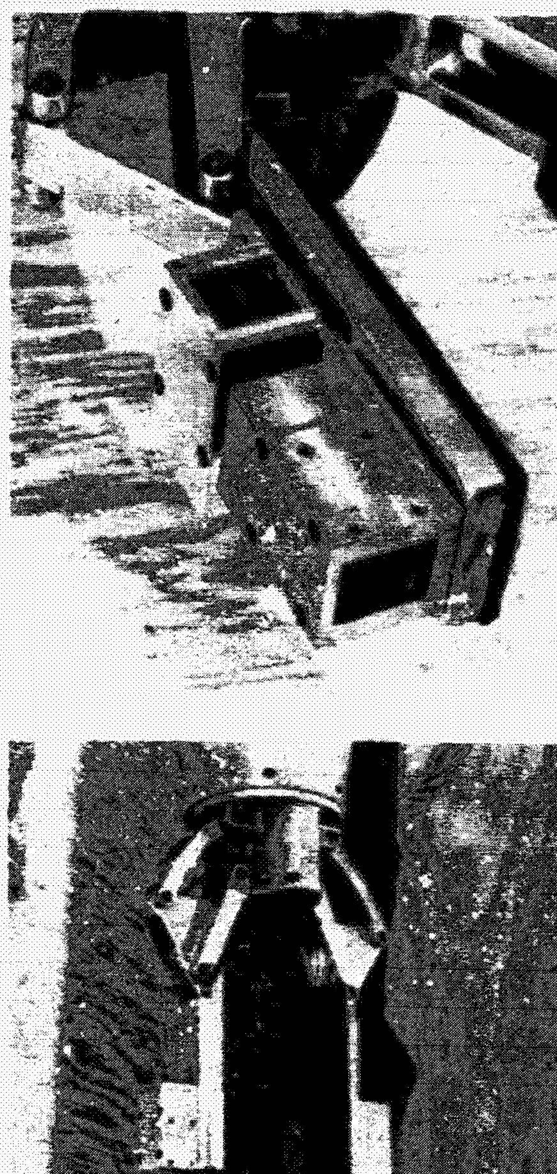

Figure 10. Proximity Sensor Arrangements

Figure 11. Typical Problem of Terminal Approach and Grasping

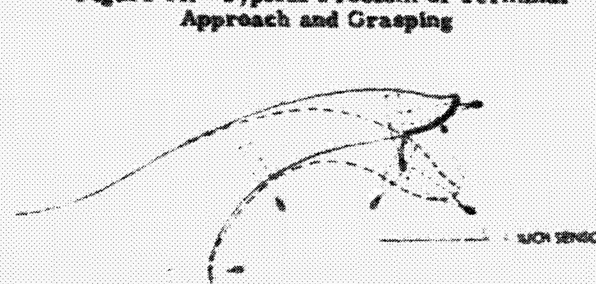

Figure 12. Schematic of Possible Arrangements of Mini-Proximity Sensors and Touchsensors to Improve Prehension Capability of Artificial Hands.

minimum of control instructions. Further, the controller in both applications should perform in a largely unarranged environment with changing conditions, and it should comply with a variety of required motion patterns. In both control cases, the information processing ability of the operator should be supported by appropriate technical information processing using for instance, a special purpose minicomputer. It is also required in both cases that the decision load be optimally shared between the operator and the external controller.

It is interesting to note that a severely disabled person can relatively well (in comparison to his handicap) describe verbally how to proceed to perform a manual task using a prosthetic arm/hand system. The question is now how to design a control "language" for artificial arm/hand control which is natural and simple for a human and easy for a prosthetic machine using, for instance, a voice command system. The design and application of a natural and simple control "language" for prosthetic arm/hand control clearly invokes the connotation of a supervisory control system.

One of the primary needs of the severely handicapped (e.g. quadriplegics) is reach and manipulative capability. Patients relegated to wheelchairs are limited in their reach capability by the mobility of the chair and the chair configuration as it affects arm extension. Add to these basic limitations due to the chair, the additional constraints placed on amputees, quadriplegics, stroke victims, and other persons deficient in limbs or in limb function, and the reach and manipulative capabilities of such persons become severely impaired. The capability for extended or enhanced reach serves not only the need for object accessibility, but also serves the primary need of the handicapped, the need for independence of action. As more objects in the environment become accessible (and consequently usable) by disabled persons, the requirement for assistance decreases, consequently reducing their dependence on others.

The problem to be attacked is the loss of reach capability prevalent in persons confined to wheelchairs or beds. These persons may also be severely limited in their reach ability due to paralysis, deformation or deficiency in one or both upper limbs. A total of 85% of the important, everyday tasks identified (Ref. 1) require elbow flexion and extension, the basic constituents of arm reach. Almost all tasks (94%) require prehension or grasp of an object. To the degree that these objects are not located in close proximity to the handicapped person, he will be required to maneuver and/or reach to acquire them, or he will be dependent on someone else to retrieve them for him.

Based on the results of the investigations and developments described in the previous Section, an applications program has been initiated to develop appropriate aids for the severely handicapped using available teleoperator/robot technology. As a first step, a powered multipurpose manipulator is developed and will be mounted on a standard wheelchair as schematically indicated in Fig. 13.

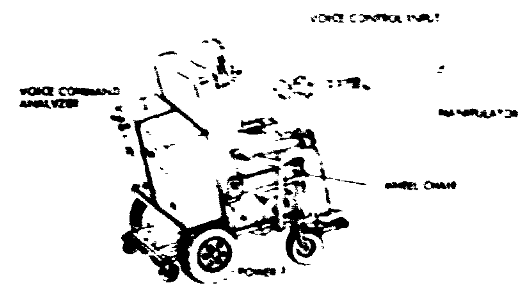

Figure 13. Powered Wheelchair with Voice Controlled Manipulator

Both the manipulator and the wheelchair are without automatic control capabilities. The wheelchair mobility is controlled through a conventional two channel bidirectional chin-switch (not indicated in Fig. 13). The manipulator is a six degree-of-freedom mechanism with the motion capabilities: horizontal ab- and adduction, shoulder flexion and extension, telescopic extension, supination and pronation, wrist flexion and extension, and grasping. The motions are voice controlled using an adaptive voice analysis and recognition system with approximately 32 words vocabulary input. Appropriate coding enables the generation of all present command requirements to have the manipulator perform simple routine tasks. However, this requires a certain training period during which the voice recognition system adapts to the peculiarities of the patient's voice and pronounciation, and the patient learns to speak the "language" the machine understands. A detailed description of the technical system characteristics will be included in a subsequent publication.

An extension of this voice controlled manipulator system is presently under consideration and entirely within present technological capabilities. In this extended system, the patient commands the manipulator sequentially through a set of desired motions which in total constitute an entire desired operation, as e.g feeding operation The sequence of these motions is then stored by the patient as a computer program in the memory of a minicomputer after the patient is satisfied that the operation is being executed to his satisfaction At the patient's disgression, the operation can then be recalled by a phrase of coded words In this manner, the handicapped will be able to "teach" the machine a whole set of stored operations which can be changed, erased, or augmented to serve his individual needs as he sees them

The use of teleoperators/robots as lunar or Mars surface roving vehicles remotely controlled from Earth suggests in certain cases a similar approach in the development of remotely controlled aids for the handicapped A first step in this direction is illustrated in Fig 14 If the patient desires to remain in bed a TV camera (or two TV cameras for stereo capability) can be attached to the arm rests by means of an appropriate structural frame The TV display and the voice

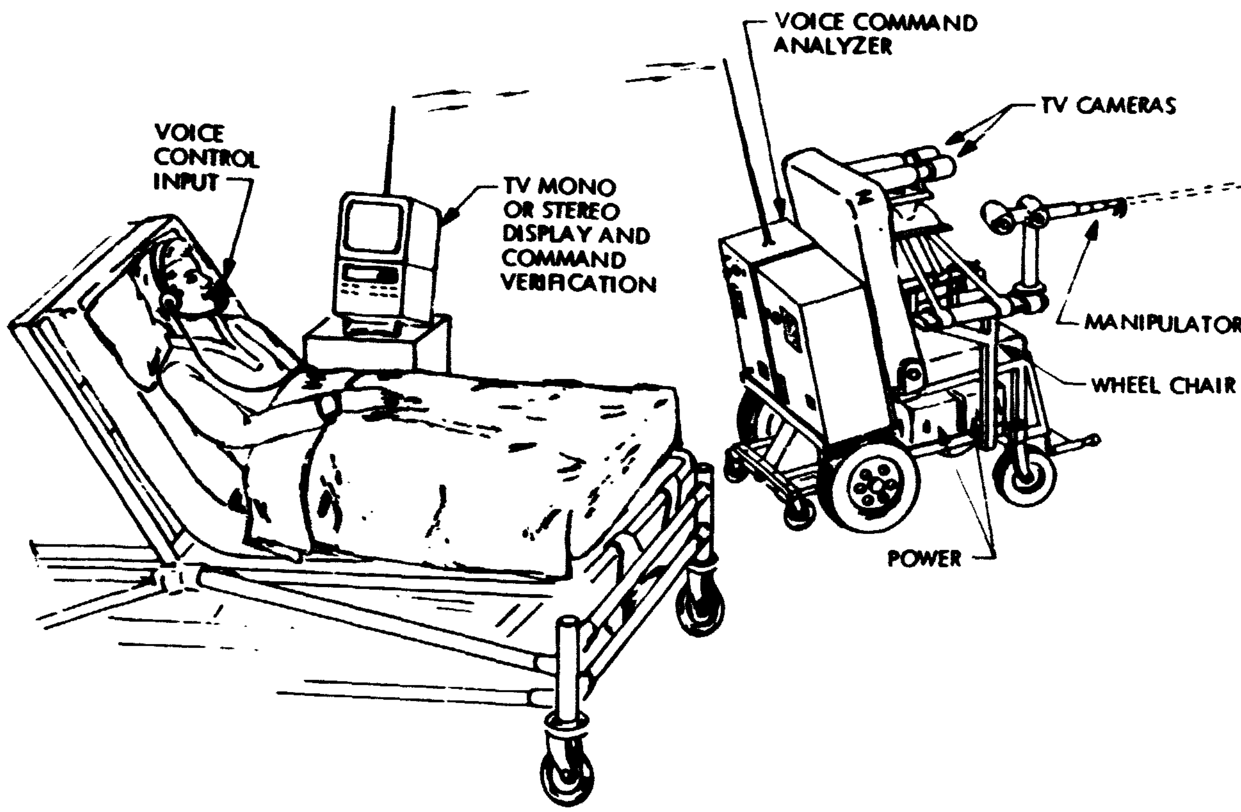

Figure 14. Powered Wheelchair with Manipulator and TV System Remotely Voice Controlled

control input remain with the patient at his bed site. Both the wheelchair and the manipulator motions are remotely voice controlled by the patient. The communication between the patient and the wheelchair is provided by a RF link enabling the patient to direct the "robot servant" to perform simple tasks in locations out of direct visual access. Investigations are presently under way to define requirements and to establish feasibility for future implementation of a working system suitable for clinical evaluation.

Conclusions

The developments of technology and techniques in the area of space teleoperator/robots introduces new possibilities in the development of prostheses and aids for the severely handicapped. This is a consequence of the similarities of many of the control and manipulative requirements imposed on the system and the system components in both the space and prosthetics related areas. The primary differences lie in the man-machine interface on the one hand and the patient-controlled device interface on the other hand. While for space (and other) applications this interface is designed for the average (or above average) healthy person in the rehabilitation area; it requires individual treatment taking account of the peculiarities of each case. Failure to recognize this may result in the rejection of the device by the patient and hence in failure of a well intentioned project.

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